Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Use of aluminium vs. iron metals in the car industry. Comparative evaluation made by using LCA and external costs methodologies

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1. Introduction & objectives

Aim of the study is the evaluation of the environmental advantages and potential reduction of impacts and thus external costs that can be achieved through substitution of the traditional iron based materials (pig iron and steel) with aluminium in the production of road transport vehicles. Data about circulating car and lorry fleets, mileage, vehicles composition, etc., refer to Italy in year 1997. Quantification of environmental impacts has been carried out by using LCI data provided with the SimaPro software.

2. Materials & methods

2.1 External costs of mobility

Externalities are defined as the effects caused by a given human activity that are not paid by those who produce them but by the entire society. In order to evaluate single externalities it is necessary to define the factors that characterize each of them. In order to carry out an overall evaluation of various types of externalities it is necessary to identify, for each of them, one or more impact parameter/pathway that can be clearly monitored. If many impact parameters/pathways are to be analysed comparatively, it is necessary to translate all them in a single unit. Usually they are evaluated for their individual monetary value **[Tab. 1]**, so that their sum provides the total external cost.

The existence of external costs determines imperfect market mechanisms. In fact, if external costs are paid by the society and are not included in the current prices, these last are not able to work correctly balancing demand and offer. External costs evaluation is a powerful tool, very useful for policy decision making not only in the field of transport; among the others, it allows to evaluate through a single parameter (the economic one) the relevance of many different effects which are other ways not comparable each other and to compare external costs per unit service (passenger kilometre, ton kilometre).

2.2 Aluminium production: physical impacts and externalities

It has been useful compare the externalities of aluminium production with those related to materials to be substituted: iron and steel. It has, therefore, carried out a comparative evaluation of the externalities of primary aluminium, recycled aluminium, iron and steel.

The quantification of impacts and thus of externalities has been carried out through the use of the SimaPro 4 software and its Database for Life Cycle Inventory. The impact parameters considered are:

- CO_2, CH_4, N_2O: as greenhouse gas;
- NO_X, PM_{10}, SO_2, COVNM, CO: as local atmospheric pollution;
- Solid waste production;
- Water consumption.

The results indicate that primary aluminium production determines impacts and thus external costs per unit mass higher than those due to iron and steel production (3,900 lire97/kg, 460 lire97/kg, 760 lire97/kg respectively—1 € = 1936.27 lire). However, recycled (80%) aluminium production determines much lower costs (700 lire97/kg), very similar to those than iron and steel.

These data indicate the importance of aluminium recovery and recycling. Besides if the aluminium stock present in the economic system could cover the demand through recycling, the externalities might became similar to those determined by ferrous metal production **[Graph. 1 and 2]**.

However, in order to compare exactly the advantages of aluminium over ferrous metals in terms of external costs, it would be necessary to proceed in terms of final use and not in term of mass. The great difference in density, in fact, might strongly play in favour of aluminium (Respectively 7.8 kg/dm^3 for iron, 2.7 kg/dm^3 for aluminium) **[Graph. 3]**.

2.3 Scenarios

It would be possible to obtain a great reduction of fuel consumption of road transport vehicles: reducing mass and improving aerodynamic may be achieved through various means, the preeminent one is the weight reduction via adoption of less dense materials (aluminium and carbon fibre instead of iron and steel).

One of the basic information used for evaluate the correlation between weight reduction and fuel consumption reduction was provided by Fiat Research Centre which states that for a 1000 kg car, a weight reduction of 10% determines a consumption reduction of about 6% (ECE-EUDC Cycle).

In the present study, two different scenarios have been simulated that include a short term modest weight reduction (10%, scenario A) and a mid term higher weight reduction (20%, scenario B): for both scenarios has been assumed the option of using mainly primary (A.1, B.1) and mainly recycled (A.2, B.2) aluminium in substitution of iron and steel.

For both scenarios impacts and external costs of production and use (mobility) have been evaluated.

Impacts and external costs for the production phase have been evaluated starting from the bill of materials of the average models for car and Pullman in Italy in 1997, and then by using the LCA methodology with the support of SimaPro4 software and its databases.

Impacts and external costs for the use phase have been evaluated starting from the study carried out by "Amici della Terra" (Friends of the Earth—Italy) on external costs of mobility in Italy in 1997 (*Lombard P.L., Molocchi A. Cutaia L. et al., I costi ambientali e sociali della mobilità in Italia, FrancoAngeli Editore, Milano 1998*).

2.3 Substitution of ferrous metals with aluminium

Based on the total weight of average vehicle and of its steel/ferrous metals and aluminium components, the amount of steel to be eliminated and substituted with aluminium can be evaluated as follow:

P is the total weight of vehicle;
K is the % of vehicle's weight reduction;
x is the amount of weight of steel to be eliminated;
y is the amount of weight of aluminium to be added.

Thus $x - y = K*P$

or, even, $\rho_{St}*V - \rho_{Al}*V = K*P$

Where ρ_{St} is the specific weight of steel (7.8 kg/dm^3), ρ_{Al} is the specific weight of aluminium (2.7 kg/dm^3)

V is the volume of steel to be substituted with a corresponding volume of aluminium, assuming, for simplicity, that a volume of steel can be replaced by a corresponding amount of aluminium, at the same function level.

Results of these elaborations in the two scenario's hypothesis (with K=10% and K=20%) are shown in **Tab.4**.

3 Results and discussions

Results show that primary aluminium production determines impacts and thus external costs per unit mass higher than those due to iron and steel production (3,900 lire97/kg, 460 lire97/kg, 760 lire97/kg respectively). However, recycled (80%) aluminium production determines much lower costs (700 lire97/kg), very similar to those than iron and steel. These data indicate the importance of aluminium recovery and recycling.

Despite the major impact generated by aluminium in the primary stage of production, these impacts are offset by lower impacts generated during the use phase by vehicles, due to lower consumption resulting from reduced weight of the vehicles.

In fact, even in the worst scenario (A1, 10% weight reduction, 75% primary aluminium), over the whole life cycle, impacts from production phase, are compensated by reduction during the use phase and consequently external costs are lower than in the base case **[Tabb. 5-6]**. Tabb. 5 and 6 represent total and specific external costs respectively.

The study indicates that a vehicle weight reduction obtained through a progressive substitution of iron with aluminium in some components determines a reduction of environmental impacts and thus external costs evaluated over the whole vehicle life, performance improved from a progressive increase in using recycled aluminium instead of primary one. The use of LCA methodology combined with external costs evaluation, is a powerful tool able to describe, in one single parameter, the economic one, many impact factors, instead of the use of the Eco- point (or similar) as synthesis parameter.

4 Conclusions

In conclusion, the study indicates that a vehicle weight reduction obtained through a progressive substitution of iron with aluminium in some components determines a reduction of impacts and thus the external costs evaluated over the whole vehicle life.

Generally speaking, aluminium melting process is less energy intensive that iron melting one, so that the external costs determined by energy consumption are much lower in the case of aluminium. Steel is an iron-carbon (0,1 e 1,8%) alloy. Its melting temperature is similar to that of iron, 1,535 °C. Aluminium melting temperature is lower: 660 °C.

The other problems related with the recycling process of car aluminium components (topic which is not included in the present study) imply investment costs which are substantially influenced by disassembly and organisation standards.

1—Tools

- Impact factors (CO_2, CH_4, N_2O: as greenhouse gas; NO_X, PM_{10}, SO_2, COVNM, CO: as local atmospheric pollution; Solid waste production; Water consumption).
- Unitary monetary values (lire97/impact factor) [tab.1]
- Total external costs (billion lire97)
- Whole mobility fleet (cars, Italy, 1997, pkm—passenger kilometers)
- Specific external costs (lire97/pkm)

2— Phisical quantification of impacts

- Bill of materials of reference models (Italy 1997) for
  - CARS
  - PULLMANS
- SimaPro4 and its LCI databases
- Emission factors of average vehicle models (for use phase—mobility)

3 — Comparative assessment of metals

[Graph. 1, 2, 3]

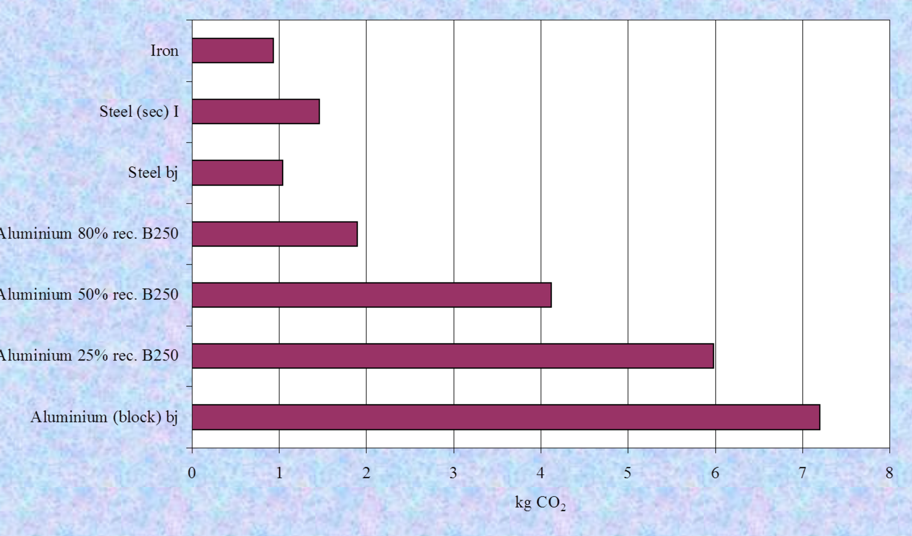
- Impact factors, external costs:
  - Iron metals
  - Primary aluminum
  - Recycled aluminum

Tab. 1— Monetary values adopted for the external costs assessment

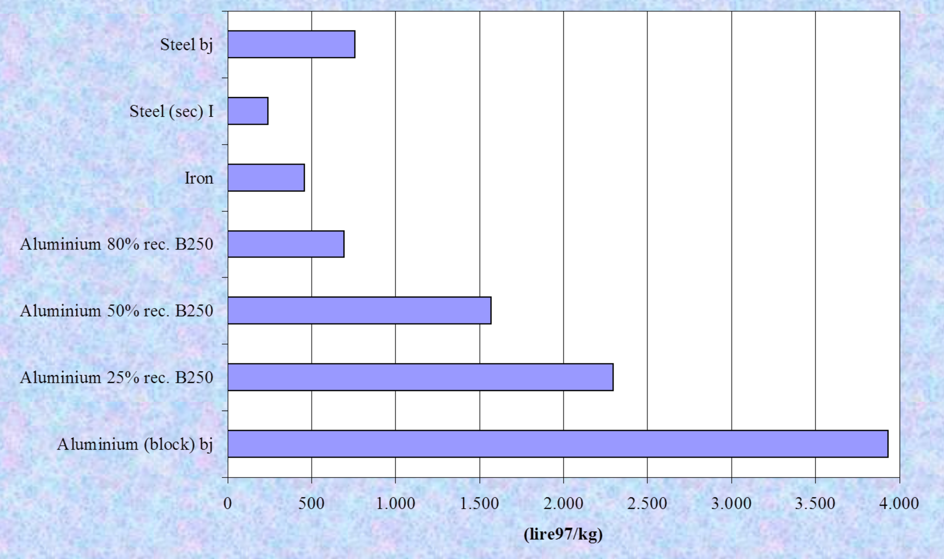
Impact factors	*unit*	*Monetary values (lire97/g, lire97/liter)*
NO_X	g	18.292000
PM_{10}	g	23.880000
SO_2	g	20.156000
COV	g	1.945000
CO	g	0.006000
CO_2	g	0.137472
CH_4	g	1.408250
N_2O	g	65.941874
solid waste	g	0.024343
water	liter	0.512000

Source: Elaboration from ExternE project et al.

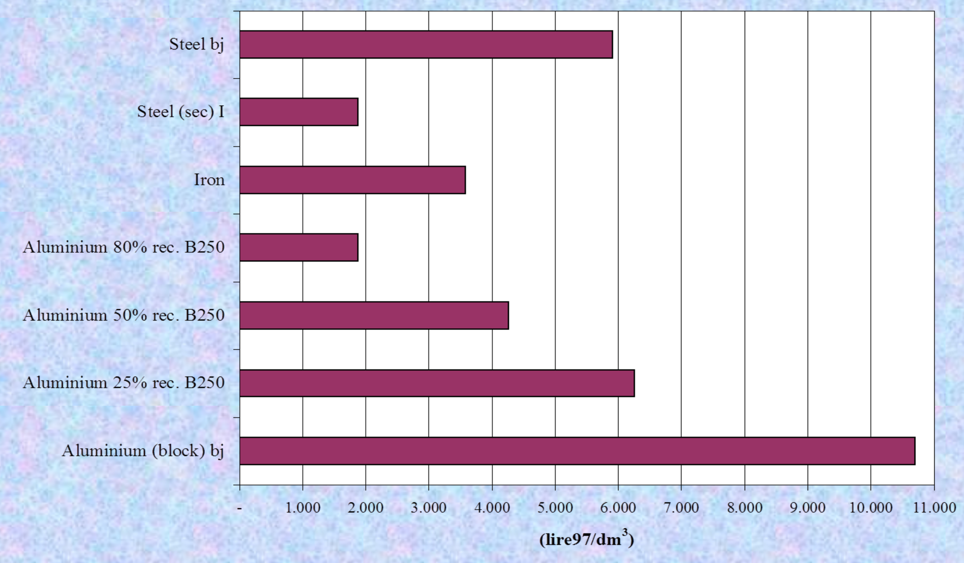
Graph 1— CO_2 emissions for the production of 1 kg of metals.



Graph 2— External costs related to the production of 1 kg of metals.



Graph 3— External costs related to the production of 1 dm^3 of metals.



4 — Scenarios

- Average models of vehicles, Italy 1997, for CARS and PULLMANS
- Impact assessment for PRODUCTION and USE phases

⇒ For Production phase: Bill of material of average models, LCA, SimaPro4 SW

⇒ For Use phase (mobility): elaboration starting from the study of external costs of mobility in Italy in 1997.

- Average life: 14 year, CARS; 20 year PULLMANS

Tab. 2 — Scenario assumptions (1)

	km/year	pass/vehic.
Cars	11.471	1,7
Pullmans	43.713	24,4

Tab. 3 — Scenario assumptions (2)

Scenarios	*Weight reduction (%)*	*Aluminium used*
A.1	10	Al rec. 25%
A.2	10	Al rec. 80%
B.1	20	Al rec. 25%
B.2	20	Al rec. 80%

Tab. 4 — Vehicle's weight in scenario's hypothesis (kg)

	Vehicle 1997		*Scenario A*		*Scenario B*	
	Car	Pullman	Car	Pullman	Car	Pullman
Vehicle	991	7,774	892	6,997	793	6,219
ferrous metals	655	3,966	503	2,772	351	1,578
aluminium	39	1,175	92	1,591	145	2,008
Weight reduction compared to the 1997 average vehicle's weight			***99***	***777***	***198***	***1,555***

Tab. 5 — Total external costs of production and mobility of cars and pullmans in Italy: Base case 1997, Scenario A and Scenario B (Glire97)

	Base case 1997		*Scenario A*				*Scenario B*			
	car	pullman	car		pullman		car		pullman	
			A1	A2	A1	A2	B1	B2	B1	B2
Production	3,043	51	3,134	2,931	54	45	3,306	2,979	57	45
Use (mobility)	112,068	4,199	109,265		4,026		106,462		3,852	
Total	***115,111***	***4,251***	***112,400***	***112,196***	***4,079***	***4,071***	***109,768***	***109,441***	***3,909***	***3,897***
Variation compared to the base case 1997 (%)			***-2.36***	***-2.53***	***-4.03***	***-4.24***	***-4.64***	***-4.93***	***-8.04***	***-8.31***

Tab. 6 — Specific external costs of production and mobility of cars and pullmans in Italy: Base case 1997, Scenario A and Scenario B (lire97/pkm)

	Base case 1997		*Scenario A*				*Scenario B*			
	car	pullman	car		pullman		car		pullman	
			A1	A2	A1	A2	B1	B2	B1	B2
Production	5	1	5	4	1	1	5	4	1	1
Use (mobility)	167	54	163		52		159		50	
Total	***171***	***55***	***167***	***167***	***53***	***52***	***163***	***163***	***50***	***50***
Variation compared to the base case 1997 (%)			***-2.36***	***-2.53***	***-4.03***	***-4.24***	***-4.64***	***-4.93***	***-8.04***	***-8.31***

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